IEEE/NASPI Oscillation Source Location Contest

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Panel Overview

- Oscillation analysis is one of the highest-value synchrophasor applications
- IEEE teamed with NASPI to host a contest for oscillation source location methods based on synthetic PMU data
- Top three performers will present their approaches:
  - Third place:
    - Team FIUBA, University of Buenos Aires
    - Pablo Gill Estevez, Pablo Marchi, Cecilia Galarza
  - First place (tie):
    - Team Woodpecker, General Electric
    - Honggang Wang, Shaopeng Liu, Gang Zheng
  - First place (tie):
    - Team RPI, Rensselaer Polytechnic Institute
    - Denis Osipov, Stavros Konstantinopoulos, Joe H. Chow

Problem Overview

- Forced oscillations occur when a piece of equipment injects a periodic disturbance into the power system
  - Example: January 11, 2019 forced oscillation event in the US Eastern Interconnection
  - Combined cycle power plant in Florida experienced a faulty input to a control system
  - Oscillations persisted across interconnection for approximately 18 minutes
  - Plant operator removed unit from service in response to control room alarms

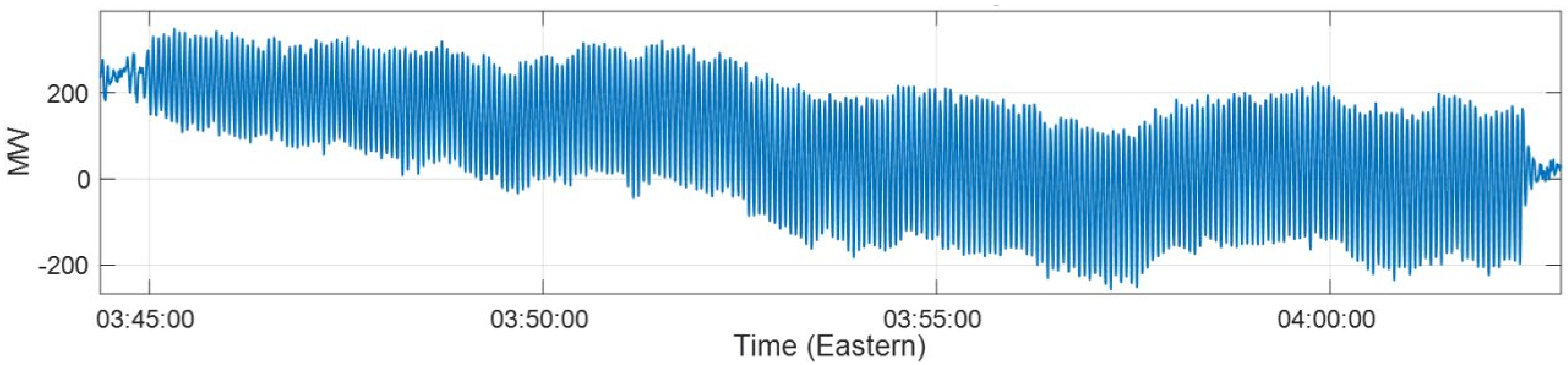

Figure credit:
NERC, "Eastern Interconnection Oscillation Disturbance," 2019, https://www.nerc.com/pa/rrm/ea/Documents/January_11_Oscillation_Event_Report.pdf.
[Source: AEP]

Problem Overview

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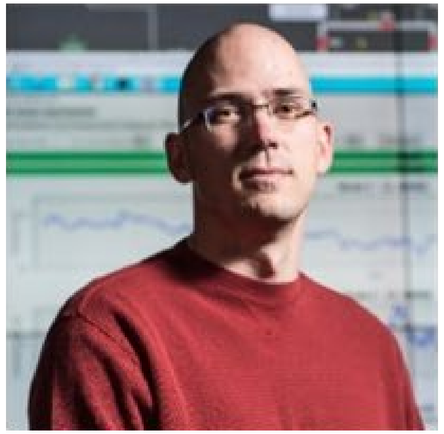
  - Combined cycle power plant in Florida experienced a faulty input to a control system
  - Oscillations persisted across interconnection for approximately 18 minutes
  - Plant operator removed unit from service in response to control room alarms
- Response times can be reduced with oscillation source location tools
  - Once responsible equipment is identified, corrective action can be taken
- Source location is a challenging problem
  - Amplitude not always largest at the source
  - Sources are varied
- Many solutions have been proposed

Contest Overview

- Objectives
  - Help academia and vendors further develop and improve source localization tools
  - Help utilities identify and evaluate tools for practical use
- Joint effort by IEEE's Oscillation Source Location Task Force (OSL-TF) and NASPI
- Participation: 60 sign-ups, 21 submissions
- Special thanks
  - Contest coordinator: Frankie Zhang (ISO New England)
  - Web support: Kai Sun (UTK), Teresa Carlon (PNNL)
  - WECC-240 bus base case: Jin Tan and the rest of the NREL team
  - TSAT simulation technical and license support: Powertech Labs

Contest Committee

Ning Zhou
(Binghampton Uni.)

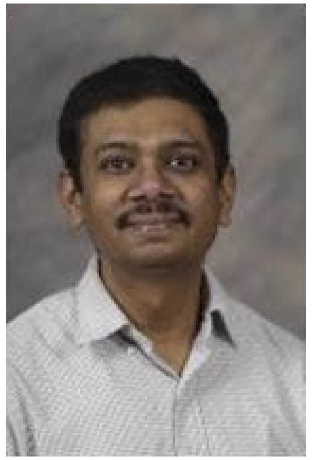


Jim Follum
(PNNL)

Athula Rajapakse
(Uni. of Manitoba)

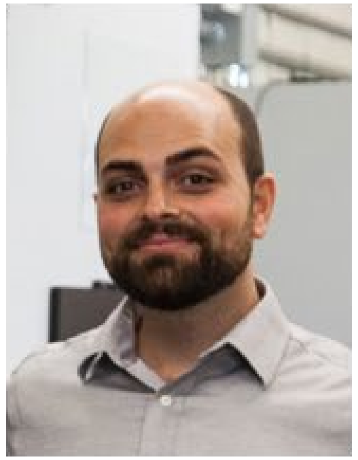
Bin Wang
(NREL)

Slava Maslennikov
(ISO-NE)



Mani Venkatasubramanian
(WSU)

Evangelos Farantatos
(EPRI)

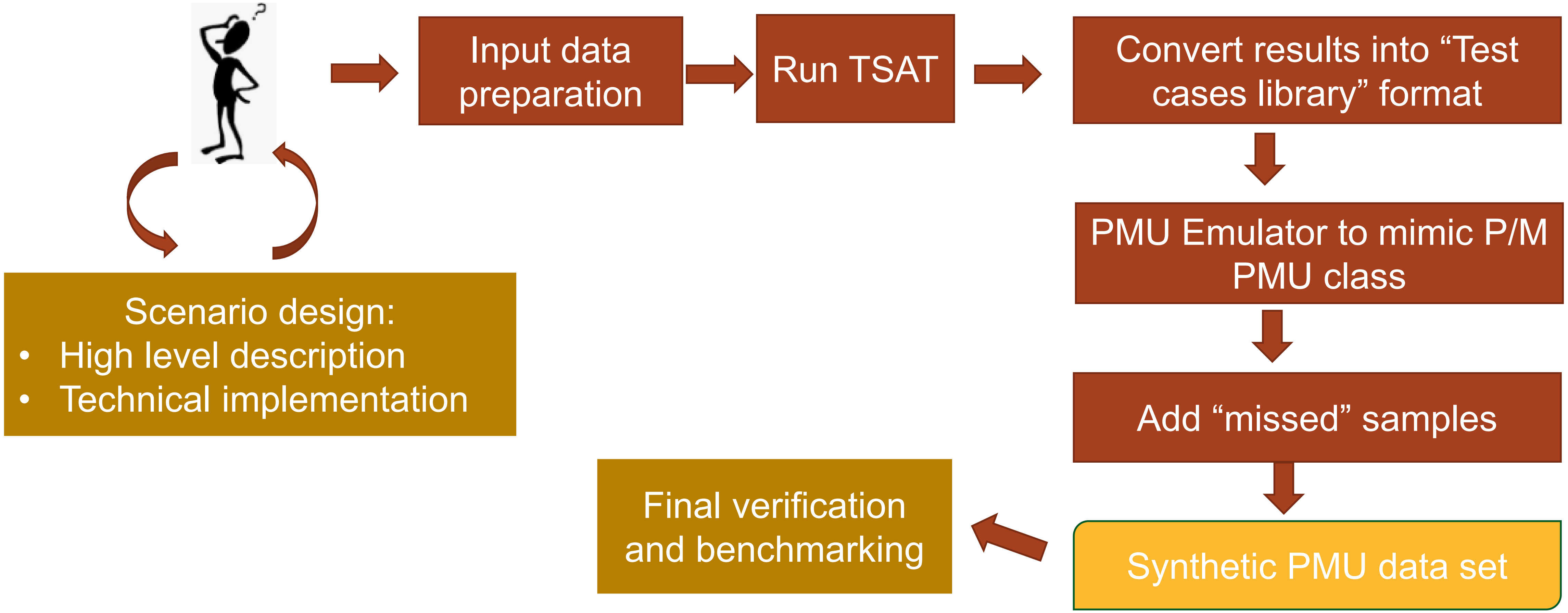


Jeff Bloemink
(Powertech Labs)

Philosophy for Creation of Simulated Cases

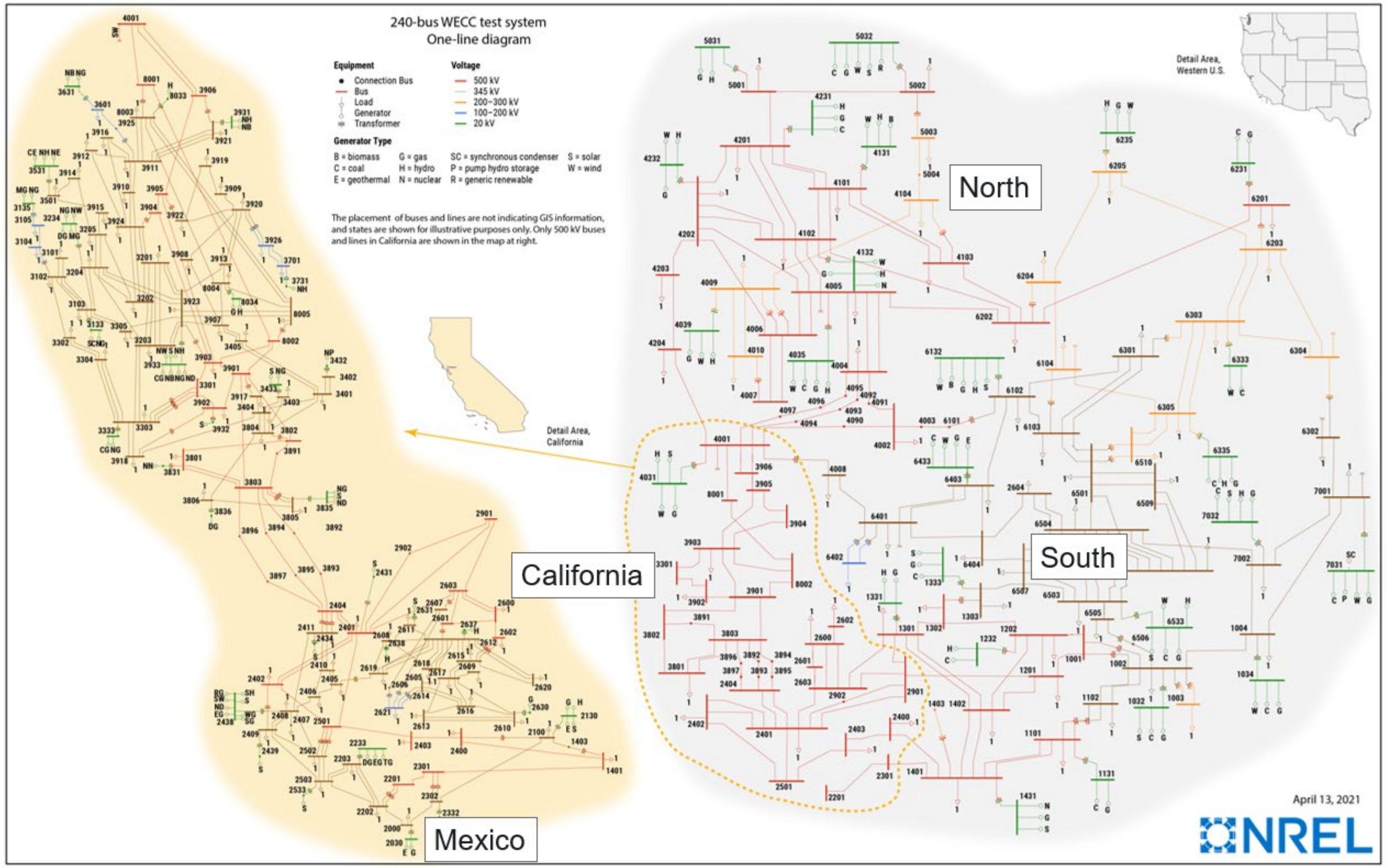
- Realism
  - Mix of local and interarea natural oscillations
  - Realistic modeling of all system components including “colored noise”
  - Synthetic PMU measurements by time-domain simulation
    - Partial system observability by PMUs
    - P/M PMU class mix; missed samples
- Properties of FO:
  - Source located at Generator (Governor & Exciter), Load, HVDC
  - Variable magnitude and frequency
  - Obfuscated onset
  - Multiple sources; resonance with natural modes
  - Harmonics
  - Strong interaction with controls
- Avoid bias for any known source locating method

Case Creation Data Flow Process



Power System

- NREL's new 240-bus WECC model
  - https://www.nrel.gov/grid/test-case-repository.html
  - Four areas: North, South, California, Mexico
  - 109 synchronous generators



Features of 13 Test Cases

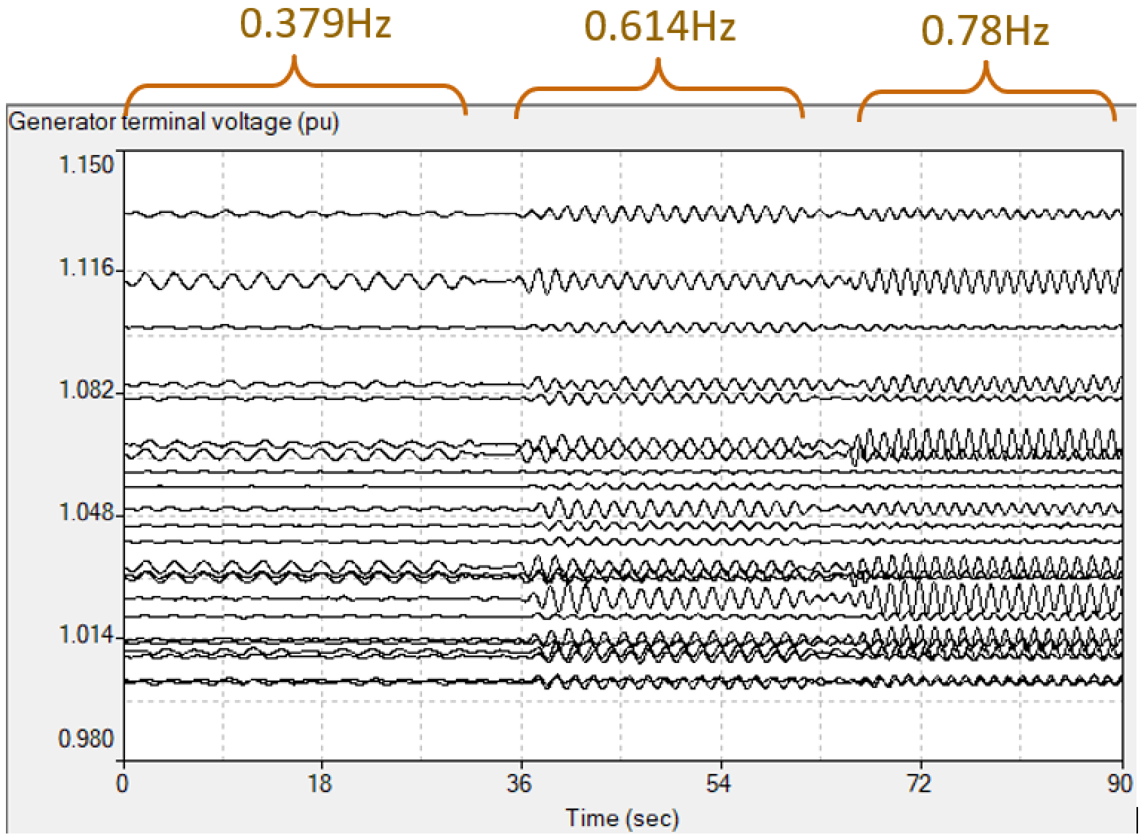
Case	Key Features
1	Easy case to “warm up”
2	Observable source; resonance with local mode
3	Non-observable source in the exciter; resonance with system-wide inter-area mode
4	Non-observable source in the governor; resonance with system-wide inter-area mode
5	Variable frequency of FO
6	Non-observable source; resonance with local mode
7	Source in the exciter; strong interaction with controls

Case	Key Features
8	Observable source; resonance with regional inter-area mode
9	2 sources: (1) FO source in the governor, (2) wrong tuning of PSS in another generator
10	2 sources of FO resonating with local and inter-area modes
11	Source of FO in Load
12	Rectangular shape of forced signal creating wide spectra of oscillations
13	Source of FO in HVDC

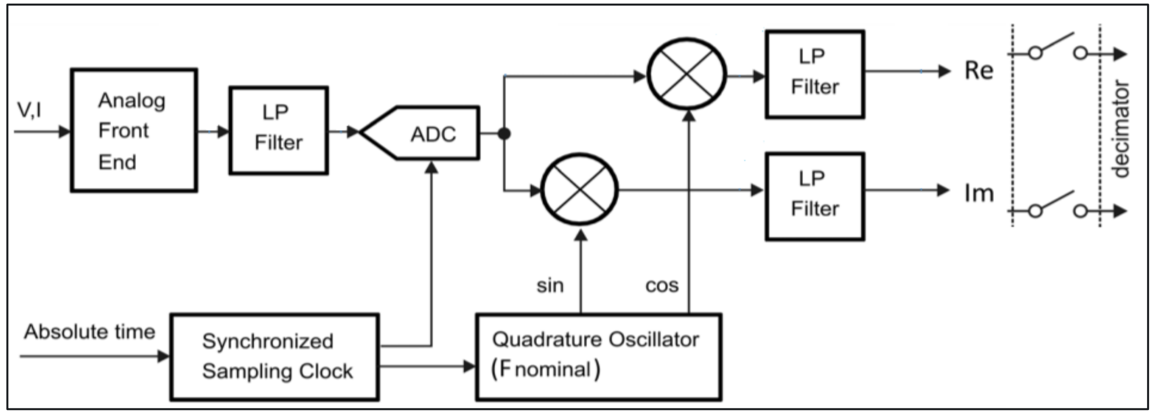
- Largest MW magnitude oscillation not in the source
- System disturbance obfuscating the FO onset

14th Case & PMU Emulator

- To investigate sensitivity of participants' OSL algorithms to PMU filtering
  - No scoring for 14th test case
- FO with single source and 3 frequencies
- Scenarios
  - Mix P/M Class PMUs
  - All P Class PMUs
  - All M Class PMUs
- EPRI's PMU Emulator
  - Models PMU signal processing
  - Input: Simulation output of electromechanical or EMT simulators (e.g., TSAT or PSCAD)



PMU Signal Processing



Data Provided to Participants

1. Model with system conditions similar to those used in simulations (PSS/E format)
   - Important for use of Model-based and Machine Learning methods
2. For each of 13 cases: synthetic PMU measurements (TSAT simulation output) (txt files)
   a) Bus voltage magnitude
   b) Bus voltage angle
   c) Line current magnitude
   d) Line current angle

Participants were required to:

- **Identify the source of oscillation (Area, Bus, Equipment type, Controller type)**
- **Submit solution by using a provided template document**

OSL Methods Used by 21 Contestants

Group #	Description
1	**Energy-based methods** (DEF, Transient energy, Dissipating potential, Energy supply on port)
2	**Oscillation shape and magnitude** (Phase relation at the onset of oscillation, Magnitude of oscillation, Mode shape)
3	**Machine Learning and Model-based analytics** (ML pattern recognition, Spectral estimate, Ensemble of analytical estimates, Graph neural network, Advanced statistical learning)
4	**Cross Power Spectra Density** (energy-based approach is the core)

Summary of OSL Contest Results

Winners; close to 100% performance

Team		1/2	1/2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Score		110	110	99	82	77	76	71	68	62	57	55	44	47	46	45	42	38	37	25	18	17
Used Method	1		X	X	X	X	X	X	X	X		X									X	
	2										X	X					X			X		
	3		X	X	X								X	X	X	X		X	X			X
	4	X																				

Methods
1: Energy-based
2: Oscillation shape and magnitude
3: Machine Learning and Model-based analytic
4: Cross Power Spectra Density

Conclusions

Energy-based methods are most efficient

Details of implementation could be critical

Team	1/2	1/2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Score	110	110	99	82	77	76	71	68	62	57	55	44	47	46	45	42	38	37	25	18	17
Used Method 1		X	X	X	X	X	X	X	X		X									X	
Used Method 2										X	X					X			X		
Used Method 3		X	X	X								X	X	X	X		X	X			X
Used Method 4	X																				

Complementary use of ML and Model-based method seems to be beneficial

ML and Model-based method are less efficient

Methods
1: Energy-based
2: Oscillation shape and magnitude
3: Machine Learning and Model-based analytic
4: Cross Power Spectra Density

PMU Class Sensitivity Test Results, Case 14

- PMU filtering for low frequency FO (<1Hz) is not expected to affect the results much
- Results of 11 participants (from 13 submitted) are NOT sensitive to PMU class
- Results of 2 participants differ depending on PMU class

	Number of Answers			
Method	All Correct	Some Correct	All Wrong	Variation
1: Energy-based	5	1		1
2: Oscillation shape and magnitude			1	
3: Machine Learning and Model-based analytic		1	4	1
4: Cross Power Spectra Density	1			

A Lasting Resource

- Contest website: http://web.eecs.utk.edu/~kaisun/Oscillation/2021Contest/
- NREL's WECC 240-bus model: https://www.nrel.gov/grid/test-case-repository.html
- Test case library: http://web.eecs.utk.edu/~kaisun/Oscillation/
  - 2016 simulation cases based on WECC 179-bus model
  - Field-measured cases
  - IEEE-NASPI contest cases and data set-ups for simulation: http://web.eecs.utk.edu/~kaisun/Oscillation/contestcases.html

Please consider using the test case library when testing and **publishing**

Pacific Northwest
NATIONAL LABORATORY

Thank you